High-impact papers published in journals listed in the field of chemical engineering

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ABSTRACT

The Essential Science Indicators (ESI) database of Thomson Reuters is widely used to evaluate and identify important, high-impact papers, but few researches have looked at attributes of the ESI database. Using the category of "chemical engineering" as an example, characteristics of the ESI database were described, and distributions of document type, language of the paper, and journal of publication were reported. Five indicators, total number of papers, first-author papers, corresponding-author papers, independent papers, and collaborative papers, were applied to evaluate publications by country, institution, and author. In addition, the number of authors cited, number of institutions cited, number of countries cited, number of subject areas cited, and number of journals cited were also used to evaluate highly-cited ESI papers. Results showed that journals with a higher impact factor did not necessarily to have more papers in the ESI. The most highly cited ESI papers had fewer authors, were more likely to be single-country papers, and in general had not yet reached a citation peak, or had an extended citation peak over several years. Self-citation does not appear to be an issue among them. The ESI database only includes papers that were published within the last ten years, and likely excludes some top-cited papers even before their citation peak is reached. We suggest that ESI criteria should be amended to include all papers but only consider citation frequencies within the last ten years.

Keywords: Essential Science Indicators (ESI); Chemical engineering journals; High-impact papers; Research productivity; Scientomerics; Bibliometrics.

INTRODUCTION

In 2002, Essential Science Indicators (ESI) database was developed as a research tool in the Web of Science. It provides bibliometric information on papers that rank in the top 1% of citation frequency in the 10-year period survey for each field of research (Garfield 2002). Thus, ESI database provides researchers access to a unique and comprehensive compilation of essential science performance statistics and science trend data. Furthermore, it permits quick and convenient identification of important researchers and papers in a subject category. As ESI database became available, researchers have used it in evaluating research performance. Past studies have used it in evaluating an institution (Pouris 2007), a country (Hickie et al. 2005), or a country (Razzouk et al. 2007). Some have used it for international comparisons of research performance (Soteriades and Falagas 2005; Csajbok et al. 2007; Hu and Rousseau 2009), or in analyzing the trend of an individual subject category (Nah et al. 2009). Despite its widespread use in research evaluation, surprisingly few researched has examined the attributes of ESI database. Some approaches can be used in evaluating ESI papers. Distributions and bibliometric characteristics by journal, country, institution, and authors can be presented. Bibliometric characteristics such as total papers, impact factors, collaboration pattern, and authorship can be analyzed. Authorship has been regarded as an important indicator for academic evaluation (Baethge 2008). In general, the first author performs most of the research, and is generally most responsible for the manuscript (Ho 2007), and the corresponding author, presumably, has the broadest control over the published research project (Wren et al. 2006), and is often a more-senior person, or head of the lab or project (Papalambros 2009). Both the first and corresponding authors are major contributors to a paper. Thus, when a paper is affiliated with a country or an institution, it is also important to consider the author affiliation, to identify whether it is a first-author affiliation or a corresponding-author affiliation. Moreover, collaboration attribute can be identified through author affiliation. Collaboration patterns indicate the extent of research networking, as well as interdependency among countries or institutions. Through both authorship and collaboration pattern, researchers can indicate whether the country or the institution played a significant role in publishing the paper.

Keyword is another important approach in analyzing ESI papers, and in identifying important research trends. Since ESI papers are the ones that receive the most citations, they probably include topics that are most often discussed, and distributions of words in the title within different blocks have been used to evaluate research trends (Li et al. 2009; Mao et al. 2010). Another approach in evaluating ESI papers is to look at the most highly cited papers within in the ESI database, and to identify the leading authors. Previous research has tabulated the number of times cited and citations per publication (Chiu and

Ho 2005; Li and Ho 2008). Citation trends over years can provide insights in projecting the future performance of papers. For the top papers, their influence can be assessed by the extensiveness of citations, i.e. the numbers of authors, institutions, countries, and subject areas citing this paper. The purpose of this paper is to investigate papers published in journals listed in the subject category of "chemical engineering", and to provide a comprehensive evaluative perspective that other researchers can adopt when evaluating the ESI database.

METHODS

Data were based on the online version of the Science Citation Index (SCI)-Expanded Web of Science database and the ESI of Thomson Reuters. According to the Journal Citation Reports (JCR), it indexed 6620 major journals with citation references across 173 scientific disciplines in 2008. One hundred and sixteen journals are listed in the subject category of "chemical engineering" in the JCR. All documents listed in the ESI database were collected on January 1, 2010. This covered the 10-year 10-month period of January 1, 1999 to October 31, 2009. Information, including names of authors, contact address, title, year of publication, keywords, and names of journals publishing the articles, can be downloaded via Thomson-Reuters' Web of Knowledge directly into Microsoft Excel for further data transformation. Additional coding was manually performed to categorize paper attributes, such as the number of authors, authorship information, and collaboration. Author address or author affiliation was used to determine the collaboration pattern. If an author moved from one affiliation to another, the latest institutional address was used. Papers were categorized as either single-country or internationally-collaborative papers, and as either single-institution or inter-institutionally-collaborative papers. At the country and institutional level, papers were also categorized as a first-authored paper or a corresponding-authored paper.

Papers originating from England, Scotland, Northern Ireland, and Wales were reclassified as from the United Kingdom (UK). Articles from Hong Kong were included in China. Institutions, such as the Chinese Academy of Sciences or the Indian Institute of Technology, that had several branches, and thus, several addresses, were also grouped together under one institution, since publications divided into branches would result in different rankings (Li et al. 2009). Keywords, extracted from the title, were compiled. Previous research has suggested that the analysis of titles must take into account content and function words, punctuation marks, length, and structural constructions (Herbert 1969). Thus, words in the title, but excluding prepositions, articles, and conjunctions, were segmented into single words, and the distribution of words was analyzed. To compare journals publishing these

ESI articles, journals impact factors were used. Impact factors (IFs) and 5-year IFs (IF5s) were taken from the Journal Citation Report (JCR) published in 2008. For the most frequently cited articles, citations number of each year, up to 2009, were also collected. In this study, total citations, citations per year, and the self-citation rate were also presented for top-cited papers, as well as the frequency of being cited by authors, institutions, countries, and journals.

RESULTS AND DISCUSSION

In total, 475 papers were indexed under the subject category of "chemical engineering" in the ESI database. Among them, there were 321 articles (68%), 93 reviews (20%), and 61 proceedings papers (13%). All papers were in English, published in 35 journals.

Journals

Table 1 shows the distribution of ESI papers in journals. Total papers, IFs, and rankings of 116 journals in the "chemical engineering" category, IF5, immediacy (I)-index, and number of papers in 2008 (08P) were presented. *Energy & Fuels*, published by the American Chemical Society, ranked 1st with 78 ESI papers, followed by the *Journal of Catalysis* with 51 papers, *Industrial & Engineering Chemistry Research* with 46 papers, *Combustion and Flame* with 42 papers, and *Catalysis Today* with 42 papers. The journal *Progress in Energy and Combustion Science*, which had the highest IF, did not have any paper in the ESI database. Some journals with relatively low IFs, such as *Energy & Fuels* (ranked 18th), *Industrial & Engineering Chemistry Research* (22nd), *Computers & Chemical Engineering* (27th), *Journal of Food Engineering* (15th), and *Applied Energy* (36th), did quite well in publishing ESI papers. In particular, *Chemical & Engineering News*, which ranked 90th in terms of its IF, published two papers. Interestingly, journals with higher IFs were not likely to publish ESI papers in "Chemical Engineering" category.

Among the ten most productive journals, six journals did not have an IF ranked in the top ten IFs in 2008. Although IF was often used to determine the importance of a given journal in its specific field of interest, individual papers could still be highly cited even though they were not published in high-IF journals. It was reported that the technical terminology used to describe the work, how it is situated in the problem domain for a field, using a different vocabulary to describe how the work has been received within the field, and describing its implications for a wider audience are possible reasons why a paper may be highly cited (Small 2004). As shown in "Chemical Engineering" category, it would not be appropriate to evaluate an article by the journal's IF. Evaluation of an individual paper probably should move away from using impact factor as an indicator.

Table 1: Distribution of ESI Papers in Journals Listed under Chemical Engineering

Journal Titles	**TP (%)**	**IF (R)**	**IF5**	**I Index**	**08P**
Energy & Fuels	78 (16)	2.056 (18)	2.22	0.32	585
Journal of Catalysis	51 (11)	5.167 (2)	5.407	0.658	313
Industrial & Engineering Chemistry Research	46 (10)	1.895 (22)	2.083	0.206	1148
Combustion and Flame	42 (8.8)	2.16 (14)	2.657	0.436	195
Catalysis Today	42 (8.8)	3.004 (5)	3.371	0.431	501
Journal of Membrane Science	34 (7.2)	3.247 (4)	3.673	0.397	799
Applied Catalysis B-Environmental	34 (7.2)	4.853 (3)	5.664	0.659	358
Computers & Chemical Engineering	23 (4.8)	1.755 (27)	2.431	0.335	236
Journal of Food Engineering	19 (4.0)	2.081 (15)	2.362	0.379	417
Applied Energy	13 (2.7)	1.371 (36)	1.465	0.26	96
Fuel	11 (2.3)	2.536 (7)	2.665	0.516	434
Tribology Letters	9 (1.9)	1.385 (35)	1.588	0.32	100
Chemical Engineering Journal	9 (1.9)	2.813 (6)	2.773	0.461	647
Separation and Purification Technology	8 (1.7)	2.503 (9)	2.981	0.335	397
AIChE Journal	6 (1.3)	1.883 (25)	2.334	0.282	277
Journal of Chemical and Engineering Data	6 (1.3)	2.063 (17)	1.939	0.3	547
Fuel Processing Technology	6 (1.3)	2.066 (16)	2.684	0.213	178
Journal of Supercritical Fluids	6 (1.3)	2.428 (10)	2.587	0.539	217
Chemical Engineering Science	5 (1.1)	1.884 (24)	2.177	0.351	507
Combustion Science and Technology	3 (0.63)	0.877 (56)	0.936	0.089	112
Journal of Aerosol Science	3 (0.63)	2.239 (12)	2.904	0.216	88
Process Biochemistry	3 (0.63)	2.414 (11)	3.149	0.195	210
Chemical & Engineering News	2 (0.42)	0.37 (90)	0.311	0.126	435
Desalination	2 (0.42)	1.155 (42)	1.394	0.155	747
Journal of Industrial and Engineering Chemistry	2 (0.42)	1.235 (41)	0.891	0.098	132
International Journal of Adhesion and Adhesives	2 (0.42)	1.678 (30)	1.852	0.286	49
Reactive & Functional Polymers	2 (0.42)	2.039 (19)	2.183	0.36	186
Oil & Gas Science and Technology-Revue de l Institut Francais du Petrole	1 (0.21)	0.699 (66)	1.015	0.075	53
Journal of Adhesion Science and Technology	1 (0.21)	0.869 (57)	1.122	0.058	120
Minerals Engineering	1 (0.21)	1.022 (49)	1.25	0.19	137
Environmental Progress	1 (0.21)	1.054 (47)	1.289	0.019	52
Adsorption-Journal of the International Adsorption Society	1 (0.21)	1.237 (40)	1.269	0.146	82
Polymer Engineering and Science	1 (0.21)	1.245 (39)	1.61	0.148	291
Powder Technology	1 (0.21)	1.766 (26)	2.098	0.341	390
Plasma Chemistry and Plasma Processing	1 (0.21)	2.167 (13)	2.082	0.388	49

TP, total papers in the ESI; IF (R), 2008 impact factor; IF5, 5-year IF; I Index, immediacy index; 08P, no. of papers in 2008

Countries

Fifty-two countries published ESI papers. Table 2 presents five indicators (total number of papers, and numbers of single-country papers, internationally-collaborative papers, first-author papers, and corresponding-author papers) with rankings and percentages for countries with at least five ESI papers. The US was the leading country with 184 papers, made up 39% of all ESI papers in the chemical engineering category. Surprisingly, China, which is often criticized for its low production of high-quality papers (CITE A SOURCE), was the 2nd leading country with 48 (10%) papers, followed by Germany (32; 6.7%), Spain (30; 6.3%), and the UK (29; 6.1%). Of the 475 ESI papers published in chemical engineering, 378 (80%) were single-country publications and 97 (20%) were internationally-collaborative papers. The US produced the most single-country (138), internationally-collaborative (46), first-author (162), and corresponding-author papers (161). Even though EU countries, in general, have done well in each of the 22 fields in the ESI, none of them can successfully compete with the US (Csajbok et al. 2007). As expected, developed countries are major contributors of ESI papers. With the exception of China (2nd), Spain (4th), and South Korea (9th), the other top ten countries are G7 countries (Canada, France, Germany, Italy, Japan, the UK, and the US). G7 countries published 60% of all single-country papers and 57% of first- and corresponding-author papers. Comparing the rankings of total papers, Germany, the UK, and Korea were three countries that dropped in ranking for first- or corresponding-author papers, probably an indication that these three countries are not doing as well in taking leadership roles in research, but rely more on international collaboration. Similarly, Germany, the UK, Canada, and Italy dropped in ranking for single-country papers, probably an indication that they are not doing as well in conducting independent research, compared to other countries.

Three countries worth mention are the US, Japan, and China. The US ranked 1st in all categories, and clearly is the leader in chemical engineering. Japan ranked 10th in total papers, but improved its ranking to 5th in single-country papers, demonstrating its outstanding ability to conduct research on its own. China surpassed other developed nations, except the US, in authorship, a phenomenon not frequently observed in bibliometrics studies. Previous researches have tended to associate China with quantity, rather than quality, of publications (Glänzel et al. 2002). However, in chemical engineering, China breaks the stereotype and was the second leading country in producing high-quality papers. As it becomes more and more difficult to meet the threshold for inclusion in the ESI (Pouris and Pouris 2010), papers published by developing countries will likely to decrease. Further study can be conducted to observe the long-term trend of the proportion of papers published by developing countries in the ESI database.

Another unusual phenomenon worth noting is the role of internationally-collaborative papers. It was reported that internationally-collaborative papers dominated highly cited papers from small countries (Persson 2010). However, in the case of chemical engineering, large developed countries also had high proportions of internationally-collaborative papers. For instance, 15 of 29 papers for the UK, 11 of 22 for Canada, and 16 of 32 for Germany were internationally-collaborative papers.

Table 2: Countries Publishing ESI Papers

Country	TP	TP R (%)	FP R (%)	RP R (%)	SP R (%)	CP R (%)
USA	184	1 (39)	1 (34)	1 (34)	1 (37)	1 (47)
China	48	2 (10)	2 (8.4)	2 (8.6)	2 (9.0)	4 (14)
Germany	32	3 (6.7)	4 (4.4)	4 (4.4)	4 (4.2)	2 (16)
Spain	30	4 (6.3)	3 (5.7)	3 (5.7)	3 (5.8)	7 (8.2)
UK	29	5 (6.1)	5 (4.2)	6 (3.8)	7 (3.7)	3 (15)
Canada	22	6 (4.6)	6 (4.0)	6 (3.8)	10 (2.9)	5 (11)
France	22	6 (4.6)	6 (4.0)	5 (4.0)	5 (4.0)	8 (7.2)
Italy	20	8 (4.2)	8 (3.6)	8 (3.6)	10 (2.9)	6 (9.3)
South Korea	19	9 (4.0)	10 (2.9)	10 (2.9)	8 (3.4)	9 (6.2)
Japan	18	10 (3.8)	9 (3.2)	9 (3.2)	5 (4.0)	15 (3.1)
India	17	11 (3.6)	11 (2.7)	10 (2.9)	9 (3.2)	10 (5.2)
Greece	13	12 (2.7)	12 (2.3)	12 (2.3)	12 (2.4)	12 (4.1)
Netherlands	12	13 (2.5)	13 (2.1)	13 (2.1)	13 (2.1)	12 (4.1)
Australia	11	14 (2.3)	13 (2.1)	13 (2.1)	13 (2.1)	15 (3.1)
Switzerland	9	15 (1.9)	15 (1.5)	15 (1.5)	18 (1.1)	10 (5.2)
Denmark	7	16 (1.5)	15 (1.5)	15 (1.5)	16 (1.3)	22 (2.1)
Ireland	7	16 (1.5)	19 (1.1)	19 (1.1)	18 (1.1)	15 (3.1)
Portugal	7	16 (1.5)	15 (1.5)	15 (1.5)	16 (1.3)	22 (2.1)
Turkey	7	16 (1.5)	15 (1.5)	15 (1.5)	15 (1.9)	N/A
Belgium	6	20 (1.3)	20 (0.84)	20 (0.84)	20 (0.79)	15 (3.1)
Mexico	5	21 (1.1)	24 (0.42)	24 (0.42)	27 (0.26)	12 (4.1)
Sweden	5	21 (1.1)	22 (0.63)	22 (0.63)	20 (0.79)	22 (2.1)
Finland	4	23 (0.84)	24 (0.42)	24 (0.42)	27 (0.26)	15 (3.1)
Malaysia	4	23 (0.84)	20 (0.84)	20 (0.84)	22 (0.53)	22 (2.1)
Singapore	4	23 (0.84)	22 (0.63)	22 (0.63)	27 (0.26)	15 (3.1)
Argentina	3	26 (0.63)	32 (0.21)	33 (0.21)	27 (0.26)	22 (2.1)
Thailand	3	26 (0.63)	32 (0.21)	33 (0.21)	27 (0.26)	22 (2.1)
Venezuela	3	26 (0.63)	32 (0.21)	33 (0.21)	N/A	15 (3.1)
Austria	2	29 (0.42)	N/A	N/A	N/A	22 (2.1)

Country	TP	TP R (%)	FP R (%)	RP R (%)	SP R (%)	CP R (%)
Brazil	2	29 (0.42)	24 (0.42)	24 (0.42)	22 (0.53)	N/A
Bulgaria	2	29 (0.42)	32 (0.21)	33 (0.21)	N/A	22 (2.1)
Chile	2	29 (0.42)	24 (0.42)	24 (0.42)	27 (0.26)	32 (1.0)
Philippines	2	29 (0.42)	N/A	N/A	N/A	22 (2.1)
Poland	2	29 (0.42)	24 (0.42)	24 (0.42)	22 (0.53)	N/A
Romania	2	29 (0.42)	32 (0.21)	33 (0.21)	N/A	22 (2.1)
Russia	2	29 (0.42)	24 (0.42)	24 (0.42)	27 (0.26)	32 (1.0)
South Africa	2	29 (0.42)	24 (0.42)	24 (0.42)	22 (0.53)	N/A
Taiwan	2	29 (0.42)	24 (0.42)	24 (0.42)	22 (0.53)	N/A
Bangladesh	1	39 (0.21)	N/A	N/A	N/A	32 (1.0)
Cyprus	1	39 (0.21)	32 (0.21)	33 (0.21)	27 (0.26)	N/A
Czech Republic	1	39 (0.21)	N/A	N/A	N/A	32 (1.0)
Hungary	1	39 (0.21)	32 (0.21)	33 (0.21)	N/A	32 (1.0)
Iran	1	39 (0.21)	32 (0.21)	33 (0.21)	N/A	32 (1.0)
Israel	1	39 (0.21)	32 (0.21)	33 (0.21)	27 (0.26)	N/A
New Zealand	1	39 (0.21)	32 (0.21)	33 (0.21)	N/A	32 (1.0)
Norway	1	39 (0.21)	32 (0.21)	33 (0.21)	27 (0.26)	N/A
Pakistan	1	39 (0.21)	32 (0.21)	33 (0.21)	27 (0.26)	N/A
Peru	1	39 (0.21)	N/A	N/A	N/A	32 (1.0)
Slovakia	1	39 (0.21)	32 (0.21)	33 (0.21)	N/A	32 (1.0)
Slovenia	1	39 (0.21)	N/A	N/A	N/A	32 (1.0)
Sri Lanka	1	39 (0.21)	32 (0.21)	33 (0.21)	N/A	32 (1.0)
Tunisia	1	39 (0.21)	N/A	N/A	N/A	32 (1.0)

TP, total number of ESI papers; FP, number of first-author papers; RP, number of corresponding-author papers; SP, number of single-country papers; CP, number of internationally-collaborative papers; R, rank; N/A, not available

Institutions

In total, 468 institutions have published articles that appeared in the ESI. Of all ESI papers, 292 (61%) were single-institution papers, and 183 (39%) were inter-institutionally-collaborative papers, indicating that high-impact research in chemical engineering does not rely much on teamwork among institutions. Table 3 shows institutions with at least five ESI papers, and displays rankings and percentages of five indicators (total number of papers, and numbers of first-author, correspondence, single-institution, and inter-institutionally-collaborative papers). Among the top 19 institutions, ten (53%) are in the USA, followed by Denmark with two institutions. Australia, China, Greece, India, Portugal, Spain, and Switzerland had one institution each. The

Schlumberger-Doll Research Center topped the list with ten papers, but ranked 21st in single-institution papers. Although Princeton University, Pennsylvania State University, and Mississippi State University did not have as many papers as Schlumberger-Doll Research Center, they were the top three institutions in producing single-institution papers, demonstrating their ability to conduct independent research. Contrary to those three institutions, other leading institutions, such as the Chinese Academy of Science, CSIC of Spain, University of Queensland, Australia, and Technical University of Denmark relied heavily on collaboration. It remains to be seen if they can continue to publish high-quality papers if collaboration with other institutions diminishes. One thing worth noting is that three of the top five institutions were not universities (Schlumberger-Doll Research Center, Chinese Academy of Sciences, and CSIC of Spain), a phenomenon not frequently observed.

Table 3: Most Productive Institutions in ESI Papers in Chemical Engineering

Institution	R (TP)	R (FP)	R (RP)	R (SP)	R (CP)
Schlumberger-Doll Research Center, USA	1 (10)	2 (7)	2 (7)	21 (2)	1 (8)
Princeton University, USA	2 (8)	1 (8)	1 (8)	2 (6)	20 (2)
Chinese Academy of Sciences, China	2 (8)	7 (5)	7 (5)	5 (4)	5 (4)
Pennsylvania State University, USA	2 (8)	2 (7)	2 (7)	1 (7)	76 (1)
CSIC (Spanish National Research Council), Spain	5 (7)	5 (6)	5 (6)	5 (4)	10 (3)
Mississippi State University, USA	5 (7)	2 (7)	2 (7)	2 (6)	76 (1)
University of Queensland, Australia	7 (6)	11 (4)	12 (4)	10 (3)	10 (3)
University of California, Berkeley, USA	7 (6)	7 (5)	7 (5)	5 (4)	20 (2)
Technical University of Denmark, Denmark	7 (6)	5 (6)	5 (6)	57 (1)	2 (5)
University of Patras, Greece	10 (5)	11 (4)	12 (4)	5 (4)	76 (1)
University of Minnesota, USA	10 (5)	91 (1)	90 (1)	57 (1)	5 (4)
ETH Zentrum, Switzerland	10 (5)	11 (4)	7 (5)	10 (3)	20 (2)
Florida State University, USA	10 (5)	91 (1)	90 (1)	N/A	2 (5)
Haldor Topsøe Research Laboratories, Denmark	10 (5)	N/A	N/A	N/A	2 (5)
University of Colorado, USA	10 (5)	20 (3)	20 (3)	21 (2)	10 (3)
Indian Institute of Technology, India	10 (5)	11 (4)	12 (4)	5 (4)	76 (1)
University of Notre Dame, USA	10 (5)	7 (5)	7 (5)	4 (5)	N/A
Lehigh University, USA	10 (5)	20 (3)	20 (3)	10 (3)	20 (2)
University of Porto, Portugal	10 (5)	7 (5)	7 (5)	10 (3)	20 (2)

R, rank; TP, total number of ESI papers; FP, number of first-author papers; RP, number of corresponding-author papers; SP, number of single-institution papers; CP, number of inter-institutionally-collaborative papers; N/A, not available.

Authorship

Overall, the average number of authors per ESI paper in chemical engineering was 3.6. Among the 475 ESI papers, 60 (13%) were single-author papers, 105 (22%) had two authors, 96 (20%) had three authors, 85 (18%) had four authors, 58 (12%) had five authors, and 71 (15%) had six or more authors. There were a total of 1461 authors, among whom 1280 (88%) contributed to only one paper, 137 (9.4%) contributed to two papers, 31 (2.1%) contributed to three papers, and 13 (0.89%) contributed to four or more papers. Previous research indicated that there was an increasing percentage of articles with more than one corresponding author, or with “equal first authors” (Hu, 2009). It remained to be observed if the highly cited papers would follow the same pattern.

Table 4 shows the rankings of authors with at least four papers. US researchers dominated the list with eight of the top 13 authors. Mullins, OC from the Schlumberger-Doll Research Center (USA) had the most papers (9), followed by Anthony, EJ from Natural Resources Canada with six papers. Knothe, G had the highest number of first-author papers (4), and Mullins, OC, Song, CS and Floudas, CA had the highest number of corresponding-author papers (5).

Table 4: Top Productive Authors Ranked by Total Number of ESI Papers

Author	Institution	TPR (TP)	FAR (TP)	RPR (TP)
Mullins, OC	Schlumberger-Doll Research Center, USA	1 (9)	5 (2)	1 (5)
Anthony, EJ	Natural Resources Canada, Canada	2 (6)	32 (1)	15 (2)
Song, CS	Pennsylvania State University, USA	3 (5)	2 (3)	1 (5)
Floudas, CA	Princeton University, USA	3 (5)	5 (2)	1 (5)
Nørskov, JK	Center for Atomic-Scale Materials Physics, Denmark	3 (5)	32 (1)	4 (4)
Brennecke, JF	University of Notre Dame, USA	3 (5)	32 (1)	4 (4)
Breen, JP	Queen’s University Belfast, UK	7 (4)	5 (2)	45 (1)
Marshall, AG	Pioneer Natural Resources, USA	7 (4)	N/A	N/A
Adhikari, S	Mississippi State University, USA	7 (4)	5 (2)	N/A
Knothe, G	National Center for Agricultural Utilization Research, USA	7 (4)	1 (4)	4 (4)
Verykios, XE	University of Patras, Greece	7 (4)	N/A	8 (3)
Fernando, S	Mississippi State University, USA	7 (4)	5 (2)	4 (4)
Yu, JG	Wuhan University of Technology, China	7 (4)	2 (3)	15 (2)

TP, total number of ESI papers; TPR, rank in total number of ESI papers; FAR, rank in total number of first-author ESI papers; RPR, rank in total number of corresponding-author ESI papers; N/A, not available.

Most Frequently Cited ESI Papers

A typical article is most heavily cited during the two years after its year of publication (Garfield 1972). In some disciplines, a citation peak may continue for 2~3 years, for example in patent ductus arteriosus (Hsieh et al. 2004) and homeopathy (Chiu and Ho, 2005). The peak position depends on the research discipline and might be shifted to the 2nd (Chiu and Ho 2005), 3rd (Adams 2005), 4th (Ayres and Vars 2000), or later years (Li and Ho 2008). However, the top cited ESI papers in chemical engineering showed a variety of citation patterns. Five papers with the most number of citations up to 2009 were selected, and their annual citation patterns are presented in Figure 1. The top five papers were: “Pseudo-second order model for sorption processes”, an article in *Process Biochemistry* by Ho and McKay (1999); “On the development of proton conducting polymer membranes for hydrogen and methanol fuel cells”, in the *Journal of Membrane Science* by Kreuer (2001); “Use of CeO_2-based oxides in the three-way catalysis” a review in *Catalysis Today* by Kašpar et al. (1999); “Catalytic removal of NO” a review in *Catalysis Today* by Pârvulescu et al. (1998); and “Ionic liquids: applications in catalysis” a review in *Catalysis Today* by Zhao et al. (2002). Figure 1 shows that with the exception of Zhao et al. (2002), none has shown a definitive citation peak. Zhao et al.’s (2002) paper reached a peak in the 3rd year, and then steadily decreased. Pârvulescu et al.’s (1998) paper reached a citation peak in the 5th year, and the peak continued for more than 5~6 years, without showing a steadily decreasing trend. The other three papers have not yet reached a peak. For highly cited ESI papers, the peak year of citation can shift to a much later year. Figure 1 also shows that citation patterns of articles with a strong upward trend distinctively differ from those of reviews. One interesting point is that for three of the top-5 highest-cited ESI papers in chemical engineering, there was no sign of decay in citation frequency, unlike for most publications. Despite continuing to receive high citations, they will be excluded from the ESI database once they have been published after the 10-year limit.

Figure 2 shows annual citations of papers that had more than 90 citations in 2009. These papers exhibited sharp increases in their citation rates and are likely to be leaders in citations in the future. The top paper was by Ho and McKay (1999) from Hong Kong University of Science & Technology (China), followed by a review from Kreuer (2001) from the Max-Planck-Institut für Festkörperforschung (Germany), and an article by Gasteiger et al. (2005) from General Motors Corporation (USA). Overall, review papers dominated the leader board, but showed smaller growth rates in citations than articles.

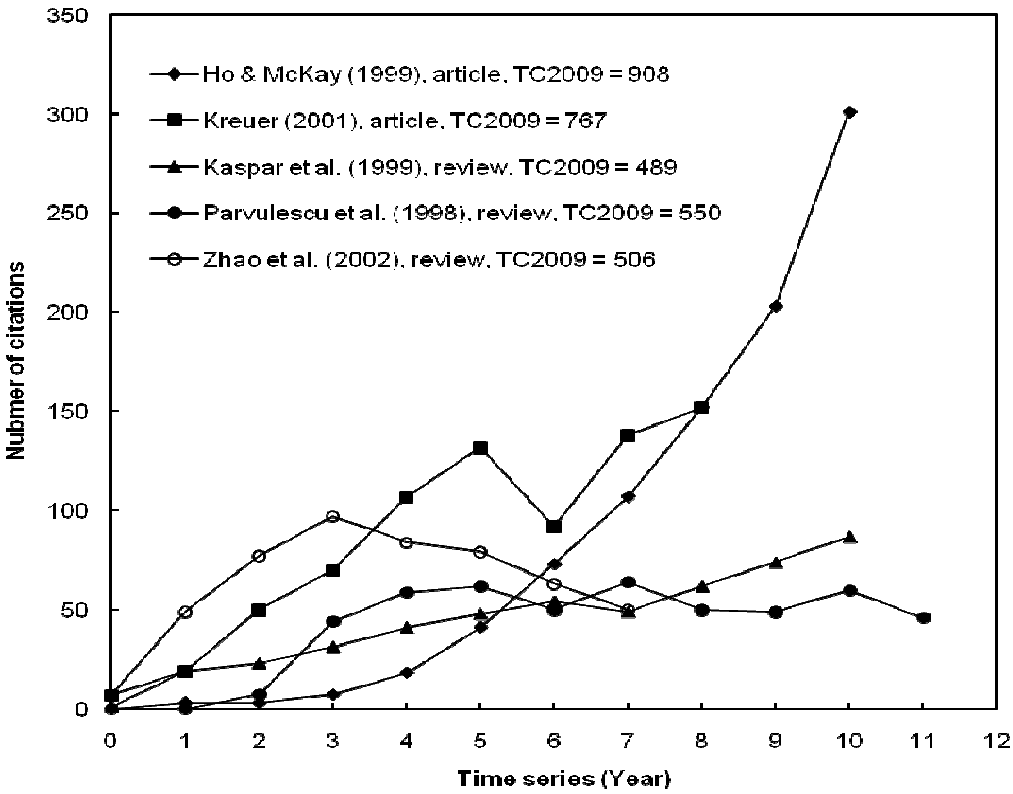

Figure 1: Most Frequently Cited ESI Publications (TC2009)

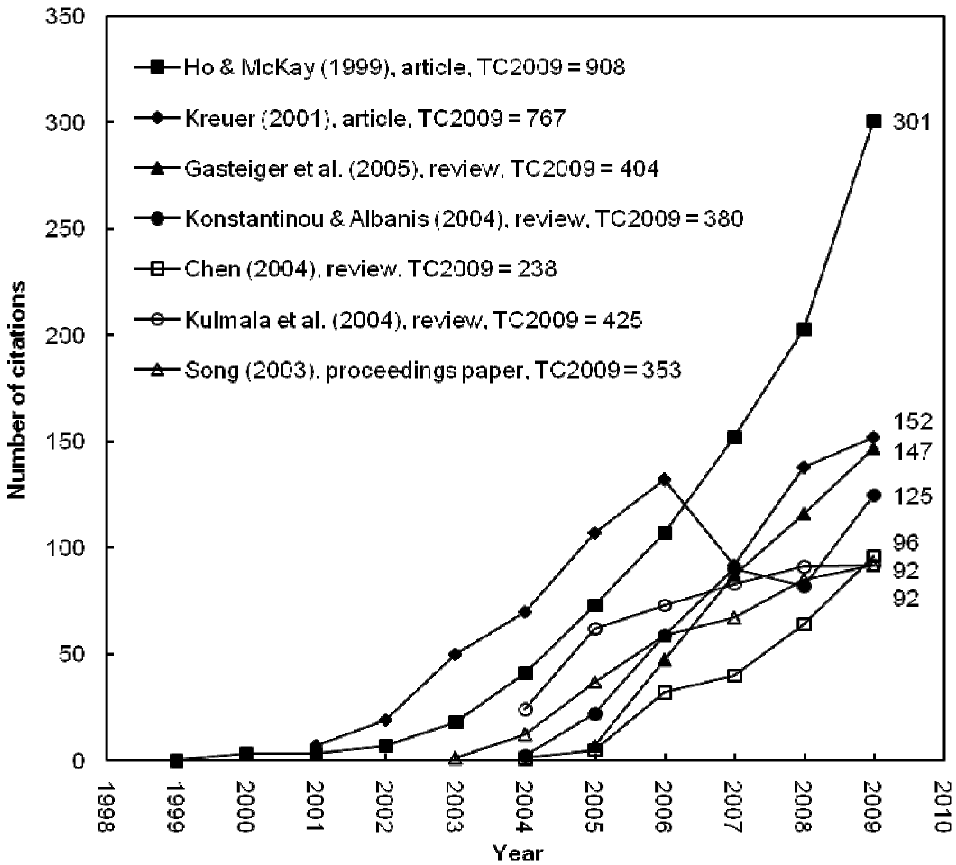

Figure 2: Life of the Most Frequently Cited ESI Papers in 2009 (C2009 > 90)

Table 5 shows the extent of influence of leading articles with at least 300 citations. Four indicators (the numbers of institutions cited, countries cited, journals cited, and subject areas cited) are presented in this study. Fifty percent of articles were published in the *Journal of Membrane Science*. Four articles were from Germany, and only one paper was an internationally-collaborative article. The top article by Ho and McKay (1999) had been cited 908 times by 1905 authors from 554 institutions in 176 journals. Previous research indicated the possibility of "treadmills of self-citation" and author self-citations among papers with high citations (Herbert 1969; Borgman and Furner 2002). However, another perspective argued that self-plagiarism occurs when authors duplicate their own previously published ideas, text, equations, or figures without citation, and probably should be avoided (Noè and Batten, 2006). While arguments continue about self-citation (Brennecke and Maginn 2001), they are still fully justified (Baird and Oppenheim 1994). Regardless, among the most highly cited articles in Table 5, only three papers had a self-citation rate of higher than 10%.

Keywords in the Title

Analyses of title words seemed to reveal three major area of research among ESI papers in chemical engineering. In total, 126 paper titles (27%) referred to catalysis: catalysts (54), catalytic (23), photocatalytic (14), catalysis (13), catalyst (11), photocatalysis (4), catalyzed (4), photocatalyst (3), photocatalysts (2), alkali-catalyzed (1), alkaline-catalyzed (1), lipase-catalyzed (1), metal-catalysed (1), noncatalytic (1), and catalyst-free (1). Eighty-three titles (17%) referred to fuels: fuel (44), biodiesel (29), fuels (13), fuel-rich (2), fueled (2), bio-oils (2), fuel-cell (1), biofuel (1), fuel-lean (1), biodiesel-ethanol (1), bioethanol (1), and bio-oil (1). Seventy titles (15%) referred to oxidation: oxidation (39), oxide (12), dioxide (9), oxidative (8), oxides (8), monoxide (3), cuznal(Zr)-oxide (1), ammoxidation (1), oxidations (1), oxide-based (1), oxide-supported (1), oxidised (1), oxidized (1), peroxide (1), and phenoloxidase-like (1).

Table 5: Top Cited Articles from Publication to 2009

Paper	NA	AU	IN	CT	SA	NJ	C/Y	Journal	Country	TC2009	TSC2009 (SR)
Ho and McKay (1999)	2	1905	554	58	57	176	83	Process Biochemistry	China	908	31 (3.4)
Kreuer (2001)	1	1702	464	44	37	139	85	Journal of Membrane Science	Germany	767	16 (2.1)
Kerres (2001)	1	1071	327	42	30	111	50	Journal of Membrane Science	Germany	446	13 (2.9)
Wang et al. (2002)	5	880	237	30	26	94	48	Journal of Membrane Science	USA	384	54 (14)
Brennecke and Maginn (2001)	2	732	240	37	37	126	38	AIChE Journal	USA	342	19 (5.6)
Schubert et al. (2001)	6	910	240	36	22	78	37	Journal of Catalysis	Germany Switzerland	329	13 (4)
Gross and Sadowski (2001)	2	545	196	35	26	51	35	Industrial & Engineering Chemistry Research	Germany	317	35 (11)
Zaidi et al. (2000)	5	743	219	30	22	83	31	Journal of Membrane Science	Canada	307	34 (11)

NA, number of authors in a paper; AU, number of authors cited; IN, number of institutions cited; CT, number of countries cited; SA, number of subject areas cited; NJ, number of journals cited; C/Y, citations/year; TC2009, total citations from publication to 2009; TSC2009, self-citations from publication to 2009; SR, self-citation rate.

CONCLUSIONS

We found 475 ESI papers, all in English, in three document types (articles, reviews, and proceedings papers), in 35 journals listed in the subject category of chemical engineering in the JCR of 2008. Thirty-seven percent of these papers were published in three journals, *Energy & Fuels*, the *Journal of Catalysis*, and *Industrial & Engineering Chemistry Research*, not all of which have high IFs. This provides additional evidence that high impact journals may not necessarily produce more top-cited papers, and the practice of using journal impact factor as an indicator of a research quality may mislead research policy.

The USA ranked top in five indicators (total number of papers, and numbers of first-author, correspondence, independent, and internationally-collaborative papers) followed distantly by China and Germany, which ranked the top two for internationally-collaborative papers. China, not known for quality research, performed quite well in the category of chemical engineering. Although recent research policies have place significant emphasis on international collaboration, the most highly cited ESI papers had fewer authors, and were more likely to be single-country papers. Self-citation does not appear to be an issue among them. The most highly cited ESI papers generally had not reached a citation peak, or had extended citation peaks over several years. Three of the top five most highly cited ESI papers showed no sign of decay in citation frequency, even after 8 – 10 years. The ESI database only includes papers that were published within the last ten years. Such criteria would likely exclude three of the top five papers in chemical engineering from the database within three years, even before a citation peak is reached. We suggest that the criteria to be included in the ESI database should be amended to include all papers, regardless of article life, but only consider citation frequencies within the last ten years, so that papers continue to receive high numbers of citations more than ten years since publication can still be included.

REFERENCES

Adams, J. 2005. Early citation counts correlate with accumulated impact. *Scientometrics*, Vol. 63, no. 3: 567-581.

Ayres, I. and Vars, F.E. 2000. Determinants of citations to articles in elite law reviews. *Journal of Legal Studies*, Vol. 29, no. 1: 427-450.

Baethge, C. 2008. First Authors in Deutsches Ärzteblatt: Women are catching up. The number of female authors in medical literature is increasing, but is still considerably lower than that of male authors and corresponds to the proportion of women working in academic medicine. *Deutsches Arzteblatt International*, Vol. 105, no. 28-29: 507-509.

Baird, L.M. and Oppenheim, C. 1994. Do citations matter? *Journal of Information Science*, Vol. 20, no. 1: 2-15.

Borgman, C.L. and Furner, J. 2002. Scholarly communication and bibliometrics. *Annual Review of Information Science and Technology*, Vol. 36: 3-72.

Brennecke, J.F. and Maginn, E.J. 2001. Ionic liquids: Innovative fluids for chemical processing. *Aiche Journal*, Vol. 47, no. 11: 2384-2389.

Chiu, W.T. and Ho, Y.S. 2005. Bibliometric analysis of homeopathy research during the period of 1991 to 2003. *Scientometrics*, Vol. 63, no. 1: 3-23.

Csajbok, E., Berhidi, A., Vasas, L. and Schubert, A. 2007. Hirsch-index for countries based on Essential Science Indicators data. *Scientometrics*, Vol. 73, no. 1: 91-117.

Garfield, E. 1972. Citation analysis as a tool in journal evaluation: Journals can be ranked by frequency and impact of citations for science policy studies. *Science*, Vol. 178, no. 4060: 471-479.

Garfield, E. 2002. Highly cited authors. *Scientist*, Vol.16, no. 7: 10.

Gasteiger, H.A., Kocha, S.S., Sompalli, B. and Wagner, F.T. 2005. Activity benchmarks and requirements for Pt, Pt-alloy, and non-Pt oxygen reduction catalysts for PEMFCs. *Applied Catalysis B-Environmental*, Vol. 56, no. 1-2: 9-35.

Glänzel, W., Schubert, A. and Braun, T. 2002. A relational charting approach to the world of basic research in twelve science fields at the end of the second millennium. *Scientometrics*, Vol. 55, no. 3: 335-348.

Herbert, W.A. 1969. Treadmills of self-citation. *American Bar Association Journal*, Vol. 55, Nov: 1006.

Hickie, I.B., Christensen, H., Davenport, T.A. and Luscombe, G.M. 2005. Can we track the impact of Australian mental health research? *Australian and New Zealand Journal of Psychiatry*, Vol. 39, no. 7: 591-599.

Ho, Y.S. 2007. Bibliometric analysis of adsorption technology in environmental science. *Journal of Environmental Protection Science*, Vol. 1, no. 1: 1-11.

Hsieh, W.H., Chiu, W.T., Lee, Y.S. and Ho, Y.S. 2004. Bibliometric analysis of patent ductus arteriosus treatments. *Scientometrics*, Vol. 60, no. 2: 205-215.

Hu, X.J. 2009. Loads of special authorship functions: Linear growth in the percentage of “equal first authors” and corresponding authors. *Journal of the American Society for Information Science and Technology*, Vol. 60, no. 11: 2378-2381.

Hu, X.J. and Rousseau, R. 2009. A comparative study of the difference in research performance in biomedical fields among selected Western and Asian countries. *Scientometrics*, Vol. 81, no. 2: 475-491.

Li, J.F., Zhang, Y.H., Wang, X.S. and Ho, Y.S. 2009. Bibliometric analysis of atmospheric simulation trends in meteorology and atmospheric science journals. *Croatica Chemica Acta*, Vol. 82, no. 3: 695-705.

Li, Z. and Ho, Y.S. 2008. Use of citation per publication as an indicator to evaluate contingent valuation research. *Scientometrics*, Vol. 75, no. 1: 97-110.

Mao, N., Wang, M.H. and Ho, Y.S. 2010. A Bibliometric Study of the trend in articles related to risk assessment published in science citation index. *Human and Ecological Risk Assessment*, Vol. 16, no. 4: 801-824.

Nah, I.W., Kang, D.S., Lee, D.H. and Chung, Y.C. 2009. A bibliometric evaluation of research performance in different subject categories. *Journal of the American Society for Information Science and Technology*, Vol. 60, no. 6: 1138-1143.

Noè, L.F. and Batten, D.J. 2006. 'Publish or perish': The pitfalls of duplicate publication. *Palaeontology*, Vol. 49, no. 6: 1365-1367.

Papalambros, P.Y. 2009. First Author. *Journal of Mechanical Design*, Vol. 131, no. 7: Article Number: 070201.

Persson, O. 2010. Are highly cited papers more international? *Scientometrics*, Vol. 83, no. 2: 397-401.

Pouris, A. 2007. The international performance of the South African academic institutions: A citation assessment. *Higher Education*, Vol. 54, no. 4: 501-509.

Pouris, A. and Pouris, A. 2010. Competing in a globalising world: International ranking of South African universities. *Innovation and Creativity in Education*, Vol. 2, no. 2: 515-520.

Razzouk, D., Zorzetto, R., Dubugras, M.T., Gerolin, J. and Mari, J.D. 2007. Leading countries in mental health research in Latin America and the Caribbean. *Revista Brasileira de Psiquiatria*, Vol. 29, no. 2: 118-122.

Small, H. 2004. Why authors think their papers are highly cited. *Scientometrics*, Vol. 60, no. 3: 305-316.

Soteriades, E.S. and Falagas, M.E. 2005. Comparison of amount of biomedical research originating from the European Union and the United States. *British Medical Journal*, Vol. 331, no. 7510: 192-194.

Wren, J.D., Grissom, J.E. and Conway, T. (2006), E-mail decay rates among corresponding authors in MEDLINE: The ability to communicate with and request materials from authors is being eroded by the expiration of e-mail addresses. *EMBO Reports*, Vol. 7, no. 2: 122-127.